

Fermilab

ES&H Section

<sup>133</sup>  
RADIATION PHYSICS NOTE XXX

**Residual Gamma Emitting Radionuclides in NuMI Rock Boring Samples**

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**I. Introduction**

Early in 1997, a group consisting of David Boehlein, Gordon Koizumi, and myself met to discuss the possibility of exposing samples from test borings for the NuMI project to radiation fields representative of the fields which such rock would be exposed to during operation of the proposed underground NuMI beamline. After some discussion, it was decided that exposing several groups of rock boring samples (in the form of 6 mm thin discs) to the radiation fields at the C0 abort would probably simulate the NuMI radiation environment as well as possible within the extant accelerator system. However Beams Division personnel persuaded us that the best place for such exposures was the F17 Lambertson magnet. It was originally anticipated that the typical energy of lost beam at this point would be near the 120 GeV, which the NuMI beamline would see. Unfortunately, typical losses during this particular run turned out to be nearer 18 GeV (Ref. 1).

The rock samples tested by the AAL appeared to be amorphous combinations of shale [ $\text{Al}_2\text{Si}_2\text{O}_5((\text{OH})_4)$ ], and dolomite [ $\text{CaMg}(\text{CO}_3)_2$ ], with trace amounts of other minerals such as pyrite ( $\text{FeS}_2$ ) and calcite ( $\text{CaCO}_3$ ).

This Radiation Physics Note documents the resulting production of gamma-ray emitting radionuclides in NuMI rock boring samples from these exposures.

**II. Method.**

In order to insure that there were no naturally occurring radioactive isotopes which would interfere with assessment of accelerator induced radioactivity and to establish blank background levels of radioactivity, background spectra for rock samples from different layers were measured and analyzed. Potassium forty ( $^{40}\text{K}$ ) and naturally occurring radionuclides from the Thorium and Uranium series were observed. No accelerator-produced radionuclides were observed.

An aluminum tag accompanied each irradiated rock sample, so that estimates of the beam flux could be made. The aluminum tags were nominally 3.8 centimeter diameter discs with a thickness of 1 millimeter. A cross section of 10.7 millibarns ( $10^{-27} \text{ cm}^2$ ) was used as the production cross section for  $^{22}\text{Na}$  on aluminum by 20 GeV baryons .

Reference 2 details the methods and procedures used to place the prepared rock boring samples on the F17 Lambertson and to remove them when the irradiation was complete. Upon completion of the irradiation the samples were immediately brought to the Activation Analysis Laboratory (AAL) for analysis. The samples were logged into the AAL and mounted on self-centering plastic holders. They were then counted by a 25% relative efficiency High Purity Germanium detector at a nominal distance of 10 cm. Each spectrum was then analyzed using EG&G Ortec's GammaVision software and a specially constructed search library to generate the appropriate peak sums for each identified transition .

Spreadsheets developed at the AAL were used to transpose the peak sums extracted from each spectra into specific activities and/or estimated baryon equivalent flux. The term baryon equivalent flux reflects the fact that at the time of this RP Note, the relative composition of the radiation field at the F17 Lambertson is still not definitively known. Hence the fluxes were estimated under the assumption that all tag activation was produced by a 100% baryon field (i.e., protons and neutrons exclusively) uniformly distributed over the exposure time. If the F17 radiation field consists primarily of mesons then the calculated beam fluxes will be approximately 30% higher.

**III. Results.**

Results for the ambient background spectra produced by NuMI rock samples are presented in Table 1. No detectable accelerator produced radionuclides were observed in any of the spectra.

Three different sets of rock core samples were exposed to beam at the F17 Lambertson and then analyzed for accelerator produced radioactive isotopes. Four samples and their accompanying tags were exposed in the first irradiation (Run 1) for 30 hours beginning on 3/14/97. Gamma-ray analysis results for these samples are presented in Table 2. Fourteen samples and their accompanying tags were irradiated (Run 2) from 3/28/97 to 4/30/97.

Gamma-ray analysis results for this sample group are presented in Table 3. Six samples and their accompanying tags constituted the final (Run 3) group irradiated at F17. These samples were irradiated from 5/23/97 to 9/30/97. Gamma-ray analysis results for this group are presented in Table 4. Table 5 is a compilation of mean values for the induced specific activity per incident equivalent baryon from Tables 2 through 4 as a function of depth below grade.

Not all of the radioactive isotopes induced in the core samples are of immediate interest to the NuMI project; whether due to short half-lives, insolubility in water, or extremely low production levels. Table 6 summarizes production of primary accelerator induced radioactive isotopes in NuMI rock core samples as a function of depth below grade.

Approximate depth profiles for the production of various gamma-ray emitting radioactive isotopes in the NuMI rock can be constructed from the data presented in Table 6. Graphs 1 through 6 present the depth profiles for  $^{22}\text{Na}$ ,  $^{60}\text{Co}$ ,  $^{54}\text{Mn}$ ,  $^{46}\text{Sc}$ ,  $^7\text{Be}$ , and  $^{59}\text{Fe}$  respectively.

#### IV. Summary and Evaluation.

Production of  $^{22}\text{Na}$  and  $^7\text{Be}$  per incident equivalent baryon seems to be approximately constant as a function of depth below grade. This would seem to suggest that the material constituents from which these isotopes are produced are in approximately the same concentrations throughout the shale/dolemite rock. The  $^7\text{Be}$  is most likely produced from neutron and gamma-ray induced spallation reactions in the rock. Of some interest to the accelerator community would be the  $^{27}\text{Al}(\text{n},^7\text{Be})^{19}\text{F}$  reaction, since  $^7\text{Be}$  is virtually ubiquitous to wipers taken in the Fermilab Beams Division. Production of the  $^{22}\text{Na}$  most probably arises from direct nuclear reactions such as  $^{24}\text{Mg}(\gamma, \text{d})^{22}\text{Na}$  and  $^{23}\text{Na}(\gamma, \text{n})^{22}\text{Na}$ .

Production of the other four plotted radioactive isotopes appears to rise dramatically between 200 and 300 feet below grade and then level off thereafter. This same trend is also generally seen for  $^{24}\text{Na}$ ,  $^{48}\text{V}$ ,  $^{51}\text{Cr}$ ,  $^{52}\text{Mn}$ ,  $^{44}\text{Mn}$ ,  $^{44}\text{Sc}$ ,  $^{153}\text{Sm}$ ,  $^{141}\text{Ce}$ ,  $^{233}\text{Pa}$ , and  $^{140}\text{La}$ . Induced specific activities of  $^{47}\text{Sc}$  and  $^{47}\text{Ca}$  strongly oscillate throughout the entire range of depth below grade (from 71' to 321') and  $^{43}\text{K}$  dips below detection limits at approximately 185' depth after a steady decrease in induced specific activity from a peak value of  $14.5 \times 10^{-13}$  pCi/gr./equivalent baryon at the starting depth of 71' below grade.

The  $^{24}\text{Na}$  is most probably produced from the  $^{27}\text{Al}(\text{n},\alpha)^{24}\text{Na}$  or the  $^{23}\text{Na}(\text{n},\gamma)^{24}\text{Na}$  reactions. All other radioactive isotopes with a Z number below 26 (Fe) are produced in the rock matrix via various direct nuclear reactions or nuclear spallation on constituents of the matrix. Vanadium 48 ( $^{48}\text{V}$ ),  $^{51}\text{Cr}$ ,  $^{52}\text{Mn}$ ,  $^{54}\text{Mn}$ , and  $^{59}\text{Fe}$  are probably mostly produced from iron or chromium isotopes extant in the rock matrix while the scandium isotopes ( $^{47}\text{Sc}$ ,  $^{46}\text{Sc}$ ,  $^{44}\text{Mn}$ , and  $^{44}\text{Sc}$ ),  $^{47}\text{Ca}$  (daughter  $^{47}\text{Sc}$ ), and  $^{43}\text{K}$  are mostly produced from the calcium isotopes resident in the rock matrix. It was established from visual inspection of the rock samples that iron (as pyrite) and calcium (as dolemite and calcite) are present in some of the rock matrix strata.

Trace impurities within the rock matrix most likely provide the scattering centers for production of the heavier element radioactive isotopes observed, i.e.,  $^{153}\text{Sm}$ ,  $^{141}\text{Ce}$ ,  $^{233}\text{Pa}$ , and  $^{140}\text{La}$ . It is possible that the  $^{233}\text{Pa}$  is produced from the ( $\text{n},\text{d}$ ) and/or ( $\gamma, \text{p}$ ) reactions on naturally occurring  $^{234}\text{U}$  in the rock matrix. Although it is not as likely that the other three heavy isotopes originate from spallation reactions on Uranium or Thorium nuclei within the rock matrix, neutron induced fission could lead to their formation as cross sections for this type of reaction on  $^{234}\text{U}$  are on the order of 10 barns. Neutron capture ( $\text{n},\gamma$ ) reactions on the corresponding stable isotopes, i.e.,  $^{152}\text{Sm}$ ,  $^{140}\text{Ce}$ , and  $^{139}\text{La}$ , have cross sections which vary from 10 to 220 barns and would therefore seem probable if  $^{152}\text{Sm}$ ,  $^{140}\text{Ce}$ , and  $^{139}\text{La}$  exist in the rock matrix. If this is the primary source of  $^{153}\text{Sm}$ ,  $^{141}\text{Ce}$ , and  $^{140}\text{La}$  in the rock samples, then it is likely that some monazite or bastnasite is also present in the rock matrix. Both minerals, i.e., monazite and bastnasite, contain all three elements in stable isotopic configurations.

#### V. References

1. D. Capista, personal communication with D. Boehnlein.

2. D. Boehnlein, Boring Sample Irradiation Procedure, Fermilab NuMI project procedure, January 1997.

**Table 1**

Ambient Background for NuMI Rock Cores

Sample #	Work Request #	NUMI Core Description	Sample Mass (gm)	Sample Thickness (cm)	Sample Diameter (cm)	Total Count Time (sec)	Total Spectrum Counts *	Specific Counts (cts/gr)	511 keV Counts
970127VC01	97-017	Deep Core	33.7044	0.6	5.1	7205.8	11279	334.64	96
970127VC02	97-017	Shallow Core	55.386	0.65	6.3	7208.6	11731	211.80	111
970408VC01	97-070	S1215-71'	52.0545	0.7	6.3	7204.9	11725	225.24	95
970408VC02	97-070	S1215-94'	59.0249	0.7	6.3	7203.5	11752	199.10	74
970408VC03	97-070	S1215-121'	60.87	0.8	6.3	7208	12032	197.67	123
970408VC04	97-070	S1215-136'	56.9821	0.65	6.3	7208.2	12200	214.10	41
970408VC05	97-070	S1215-142'	54.4677	0.7	6.3	7206.3	11523	211.56	100
970408VC06	97-070	S1215-146'	62.9492	0.8	6.3	7205.9	12748	202.51	115
970408VC07	97-070	S1215-173'	60.772	0.75	6.3	7203.7	11948	196.60	95
970408VC08	97-070	S1215-186'	67.3369	0.8	6.3	7207.2	12878	191.25	92
970408VC09	97-070	S1215-196'	58.7054	0.7	6.3	7206.8	12577	214.24	81
970408VC10	97-070 (a)	S1215-221'	45.6009	0.65	6.3	7207.6	12544	275.08	112
970408VC11	97-070 (b)	S1215-246'	34.8267	0.4	6.3	7206.9	12652	363.28	94
970408VC12	97-070 (c)	S1215-271'	65.9523	0.85	6.3	7202.5	11990	181.80	81
970408VC13	97-070 (d)	S1215-297'	60.715	0.7	6.3	7205	13071	215.28	107
970408VC14	97-070 (e)	S1215-321'	62.1624	0.8	6.3	7204.3	12471	200.62	90
970529VC01	97-114	S1214-R13 200'	58.3542	0.7	6.3	7205.2	12152	208.25	116
970529VC02	97-114	S1214-R9 153'	62.4025	0.75	6.3	7203.7	12580	201.59	99
970529VC03	97-114	S1214-R14 200'	41.3431	0.6	6.3	7205.3	12426	300.56	117
970529VC04	97-114	S1217-R9 152.5'	63.9579	0.7	6.3	7205	13016	203.51	96
970529VC05	97-114	S1214-R6 124.5'	45.6147	0.6	6.3	7202.7	12142	266.19	110
970529VC06	97-114	S1217-R6 125'	62.2801	0.8	6.3	7205.2	13016	208.99	88
* Summed from 40 keV to 3000 keV									



**Table 2**  
NuMI Rock Cores - Run1

Fermilab Sample ID	Core ID	AAL Work Request #	Estimated Beam Flux (equivalent Baryons) (X10 <sup>13</sup> )	Error on Estimated Beam Flux (eq. Baryons) (X10 <sup>13</sup> )	Isotope	Average Specific Activitiy (pCi/gr) (X10 <sup>2</sup> )	Specific Activity Error (pCi/gr)
970318GL01	Core #1169 Run 12-1 185'	97-057			<sup>22</sup> Na	111	± 18
					<sup>24</sup> Na	458	± 76
					<sup>52</sup> Mn	25.9	± 3.9
					<sup>54</sup> Mn	18.8	± 3.1
					<sup>7</sup> Be	1366	± 222
					<sup>43</sup> K	28.6	± 4.3
					<sup>48</sup> V	18.8	± 3.5
					<sup>47</sup> Sc	60.8	± 9.9
					<sup>46</sup> Sc	9.55	± 1.57
					<sup>51</sup> Cr	68	± 12.2
					<sup>44</sup> Sc	3.49	± 0.84
					<sup>28</sup> Mg	11	± 1.83
					<sup>47</sup> Ca	31.4	± 5.3
					<sup>153</sup> Sm	22.8	± 4.1
970318GL02	Tag #5694	97-057	4.96	± 0.66	<sup>22</sup> Na	240	± 28
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970318GL03	Core #1169 Run 7-1 130'	97-057			<sup>22</sup> Na	133	± 19
					<sup>24</sup> Na	573	± 79
					<sup>52</sup> Mn	45.8	± 5.7
					<sup>54</sup> Mn	37.2	± 5.2
					<sup>7</sup> Be	1779	± 247
					<sup>43</sup> K	48.4	± 8.4
					<sup>48</sup> V	31	± 4.1
					<sup>47</sup> Sc	134	± 19
					<sup>46</sup> Sc	17.7	± 2.4
					<sup>51</sup> Cr	120	± 17
					<sup>44</sup> Sc	1.71	± 0.86
					<sup>28</sup> Mg	15.3	± 2.3
					<sup>47</sup> Ca	67.8	± 9.6
					<sup>153</sup> Sm	27	± 4.2

**Table 2**  
NuMI Rock Cores - Run1

970318GL04	Tag #5692	97-057	6.63	±	0.87	$^{22}\text{Na}$	320	±	37
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970318GL05	Core #1169 Run 8-1 138'	97-057				$^{22}\text{Na}$	125	±	18
						$^{24}\text{Na}$	498	±	69
						$^{52}\text{Mn}$	22.6	±	3
						$^{54}\text{Mn}$	18.2	±	2.5
						$^7\text{Be}$	1738	±	241
						$^{43}\text{K}$	41.7	±	6
						$^{48}\text{V}$	16.8	±	2.2
						$^{47}\text{Sc}$	114	±	16
						$^{46}\text{Sc}$	10.2	±	1.5
						$^{51}\text{Cr}$	39.5	±	8
						$^{44}\text{Sc}$			
						$^{28}\text{Mg}$			
						$^{47}\text{Ca}$	62.7	±	9
						$^{153}\text{Sm}$	18.7	±	3.3
970318GL06	Tag #5693	97-057	5.47	±	0.72	$^{22}\text{Na}$	264	±	31
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970318GL07	Core #1169 Run 6-1 107'	97-057				$^{22}\text{Na}$	105	±	15
						$^{24}\text{Na}$	568	±	84
						$^{52}\text{Mn}$	18.5	±	2.5
						$^{54}\text{Mn}$	15.2	±	2.1
						$^7\text{Be}$	1432	±	198
						$^{43}\text{K}$	52.2	±	7
						$^{48}\text{V}$	11.6	±	1.7
						$^{47}\text{Sc}$	106	±	14.7
						$^{46}\text{Sc}$	7.78	±	1.04
						$^{51}\text{Cr}$	43.6	±	7.5
						$^{44}\text{Sc}$			
						$^{28}\text{Mg}$			
						$^{47}\text{Ca}$	52	±	7.5
						$^{153}\text{Sm}$	22.9	±	4
970318GL08	Tag #5695	97-057	5	±	0.66	$^{22}\text{Na}$	242	±	28

**Table 3**  
NuMI Rock Cores -Run 2

Fermilab Sample ID	Core ID	AAL Work Request #	Estimated Beam Flux (equivalent Baryons) ( $\times 10^{13}$ )	Error on Estimated Beam Flux (eq. Baryons) ( $\times 10^{13}$ )	Isotope	Average Specific Activitiy (pCi/gr) ( $\times 10^2$ )	Specific Activity Error (pCi/gr)
970430GL01	Core S1215-297'	97-090-1			$^{22}\text{Na}$	56	$\pm$ 7.9
					$^{24}\text{Na}$	3057	$\pm$ 1116
					$^{52}\text{Mn}$	161	$\pm$ 23
					$^{54}\text{Mn}$	78.2	$\pm$ 10.9
					$^7\text{Be}$	861	$\pm$ 119
					$^{59}\text{Fe}$	23.8	$\pm$ 3.6
					$^{48}\text{V}$	81.4	$\pm$ 11.4
					$^{47}\text{Sc}$	193	$\pm$ 27
					$^{46}\text{Sc}$	56.6	$\pm$ 7.6
					$^{51}\text{Cr}$	275	$\pm$ 38
					$^{44}\text{Mn}$	35.1	$\pm$ 5.4
					$^{44}\text{Sc}$	6.13	$\pm$ 0.98
					$^{28}\text{Mg}$	309	$\pm$ 44
					$^{47}\text{Ca}$	31.6	$\pm$ 5.2
					$^{153}\text{Sm}$	280	$\pm$ 40
					$^{140}\text{La}$	47.1	$\pm$ 8.9
					$^{60}\text{Co}$		
					$^{233}\text{Pa}$		
					$^{141}\text{Ce}$		
					$^{43}\text{K}$		
970430GL04	Tag #5887	97-090-T1	2.94	$\pm$ 0.4	$^{22}\text{Na}$	140	$\pm$ 17
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970430GL01	Core S-1215-271'	97-090-2			$^{22}\text{Na}$	71.2	$\pm$ 10.1
					$^{24}\text{Na}$	3923	$\pm$ 753
					$^{52}\text{Mn}$	78.2	$\pm$ 10.1
					$^{54}\text{Mn}$	35.8	$\pm$ 5
					$^7\text{Be}$	1013	$\pm$ 141
					$^{59}\text{Fe}$	7.39	$\pm$ 1.23
					$^{48}\text{V}$	40	$\pm$ 5.4
					$^{47}\text{Sc}$	177	$\pm$ 25
					$^{46}\text{Sc}$	37.4	$\pm$ 5.2
					$^{51}\text{Cr}$	128	$\pm$ 18
					$^{44}\text{Mn}$	12.8	$\pm$ 2.8

**Table 3**  
NuMI Rock Cores -Run 2

						$^{44}\text{Sc}$	4.03	$\pm$	0.74
						$^{28}\text{Mg}$			
						$^{47}\text{Ca}$	37.9	$\pm$	6
						$^{153}\text{Sm}$	190	$\pm$	28
						$^{140}\text{La}$	39.1	$\pm$	7.8
						$^{60}\text{Co}$	1.2	$\pm$	0.38
						$^{233}\text{Pa}$	5.97	$\pm$	1.48
						$^{141}\text{Ce}$			
						$^{43}\text{K}$			
970430GL04	Tag #5888	97-090-T2	3.47	$\pm$	0.47	$^{22}\text{Na}$	165	$\pm$	20
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970430GL01	Core #S1215-246 <sup>1</sup>	97-090-3				$^{22}\text{Na}$	80.7	$\pm$	11.4
						$^{24}\text{Na}$	3074	$\pm$	606
						$^{52}\text{Mn}$	58.4	$\pm$	8.1
						$^{54}\text{Mn}$	28.8	$\pm$	4.1
						$^{7}\text{Be}$	1158	$\pm$	161
						$^{59}\text{Fe}$	6.73	$\pm$	1.37
						$^{48}\text{V}$	30.6	$\pm$	4.3
						$^{47}\text{Sc}$	191	$\pm$	26
						$^{46}\text{Sc}$	32.2	$\pm$	4.5
						$^{51}\text{Cr}$	91	$\pm$	13.2
						$^{44}\text{Sc}$	18.6	$\pm$	3.2
						$^{28}\text{Mg}$			
						$^{47}\text{Ca}$	46.2	$\pm$	7.1
						$^{153}\text{Sm}$	142	$\pm$	21
						$^{140}\text{La}$	44.3	$\pm$	7.8
						$^{60}\text{Co}$			
						$^{233}\text{Pa}$	7.33	$\pm$	1.48
						$^{141}\text{Ce}$	2.01	$\pm$	0.58
						$^{43}\text{K}$			
970430GL04	Tag #5889	97-090-T3	3.89	$\pm$	0.52	$^{22}\text{Na}$	185	$\pm$	22
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970430GL01	Core #S1215-071 <sup>1</sup>	97-090-4				$^{22}\text{Na}$	102	$\pm$	14
						$^{24}\text{Na}$	1110	$\pm$	276
						$^{52}\text{Mn}$	23	$\pm$	3.1

**Table 3**  
NuMI Rock Cores -Run 2

						$^{54}\text{Mn}$	11.2	$\pm$	1.7
						$^7\text{Be}$	1769	$\pm$	245
						$^{59}\text{Fe}$			
						$^{48}\text{V}$	16	$\pm$	2.3
						$^{47}\text{Sc}$	212	$\pm$	29
						$^{46}\text{Sc}$	13.4	$\pm$	1.9
						$^{51}\text{Cr}$	36.8	$\pm$	6.4
						$^{44}\text{Mn}$			
						$^{44}\text{Sc}$	1.59	$\pm$	0.36
						$^{28}\text{Mg}$			
						$^{47}\text{Ca}$	71.5	$\pm$	10.5
						$^{153}\text{Sm}$	29.4	$\pm$	8.5
						$^{140}\text{La}$	16.2	$\pm$	4
						$^{60}\text{Co}$			
						$^{233}\text{Pa}$			
						$^{141}\text{Ce}$			
						$^{43}\text{K}$	72.1	$\pm$	19.9
970430GL04	Tag #5900	97-090-T4	4.96	$\pm$	0.66	$^{22}\text{Na}$	236	$\pm$	28

970430GL02	Core #S1215-221'	97-090-5				$^{22}\text{Na}$	86.8	$\pm$	12.2
						$^{24}\text{Na}$	5473	$\pm$	1323
						$^{52}\text{Mn}$	58.4	$\pm$	8.1
						$^{54}\text{Mn}$	25.6	$\pm$	3.6
						$^7\text{Be}$	1368	$\pm$	190
						$^{59}\text{Fe}$	3.26	$\pm$	0.92
						$^{48}\text{V}$	30	$\pm$	4.3
						$^{47}\text{Sc}$	183	$\pm$	25
						$^{46}\text{Sc}$	20.9	$\pm$	3.1
						$^{51}\text{Cr}$	108	$\pm$	16
						$^{44}\text{Mn}$	14	$\pm$	5
						$^{44}\text{Sc}$	1.55	$\pm$	0.8
						$^{28}\text{Mg}$			
						$^{47}\text{Ca}$	45.5	$\pm$	7.1
						$^{153}\text{Sm}$	74.8	$\pm$	15.7
						$^{140}\text{La}$	16.8	$\pm$	8.1
						$^{60}\text{Co}$			
						$^{233}\text{Pa}$	5.34	$\pm$	1.43
						$^{141}\text{Ce}$			
						$^{43}\text{K}$			

**Table 3**  
NuMI Rock Cores -Run 2

970430GL05	Tag #5895	97-090-T5	4.43	±	0.59	$^{22}\text{Na}$	211	±	25
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970430GL02	Core #S1215-142'	97-090-6				$^{22}\text{Na}$	57.1	±	8.1
						$^{24}\text{Na}$	45.2	±	7.3
						$^{52}\text{Mn}$	10.3	±	1.8
						$^{54}\text{Mn}$	6.54	±	1.05
						$^7\text{Be}$	975	±	136
						$^{59}\text{Fe}$			
						$^{48}\text{V}$	6.72	±	1.15
						$^{47}\text{Sc}$	136	±	19
						$^{46}\text{Sc}$	4.28	±	0.7
						$^{51}\text{Cr}$	14.9	±	3.9
						$^{44}\text{Mg}$			
						$^{44}\text{Sc}$			
						$^{28}\text{Mg}$			
						$^{47}\text{Ca}$			
						$^{153}\text{Sm}$			
						$^{140}\text{La}$			
						$^{60}\text{Co}$			
						$^{233}\text{Pa}$			
						$^{141}\text{Ce}$			
						$^{43}\text{K}$			
970430GL05	Tag #5896	97-090-T6	2.66	±	0.36	$^{22}\text{Na}$	127	±	15
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970430GL02	Core #S1215-136'	97-090-7				$^{22}\text{Na}$	64.8	±	9.2
						$^{24}\text{Na}$			
						$^{52}\text{Mn}$	21.7	±	3
						$^{54}\text{Mn}$	12	±	1.8
						$^7\text{Be}$	1101	±	153
						$^{59}\text{Fe}$			
						$^{48}\text{V}$	12.7	±	2
						$^{47}\text{Sc}$	159	±	22
						$^{46}\text{Sc}$	11.1	±	1.6
						$^{51}\text{Cr}$	39	±	6.4
						$^{44}\text{Mg}$			
						$^{44}\text{Sc}$			

**Table 3**  
NuMI Rock Cores -Run 2

						$^{28}\text{Mg}$			
						$^{47}\text{Ca}$	51.6	$\pm$	7.7
						$^{153}\text{Sm}$			
						$^{140}\text{La}$			
						$^{60}\text{Co}$			
						$^{233}\text{Pa}$	3.62	$\pm$	1.07
						$^{141}\text{Ce}$			
						$^{43}\text{K}$			
970430GL05	Tag #5897	97-090-T7	3.1	$\pm$	0.42	$^{22}\text{Na}$	148	$\pm$	18
<hr/>									
970430GL02	Core #S1215-121'	97-090-8				$^{22}\text{Na}$	76.5	$\pm$	10.8
						$^{24}\text{Na}$			
						$^{52}\text{Mn}$	22.6	$\pm$	3.3
						$^{54}\text{Mn}$	9.93	$\pm$	1.49
						$^{7}\text{Be}$	1334	$\pm$	186
						$^{59}\text{Fe}$			
						$^{48}\text{V}$	13.7	$\pm$	2
						$^{47}\text{Sc}$	210	$\pm$	29
						$^{46}\text{Sc}$	9.46	$\pm$	1.38
						$^{51}\text{Cr}$	32.1	$\pm$	5.7
						$^{44}\text{Mn}$			
						$^{44}\text{Sc}$			
						$^{28}\text{Mg}$			
						$^{47}\text{Ca}$	65.3	$\pm$	10.1
						$^{153}\text{Sm}$	53.9	$\pm$	14.7
						$^{140}\text{La}$			
						$^{60}\text{Co}$			
						$^{233}\text{Pa}$			
						$^{141}\text{Ce}$			
						$^{43}\text{K}$			
970430GL05	Tag #5898	97-090-T8	3.33	$\pm$	0.45	$^{22}\text{Na}$	158	$\pm$	19
<hr/>									
970430GL02	Core #S1215-094'	97-090-9				$^{22}\text{Na}$	88.4	$\pm$	12.4
						$^{24}\text{Na}$			
						$^{52}\text{Mn}$	50.3	$\pm$	7.1
						$^{54}\text{Mn}$	22.5	$\pm$	3.2

**Table 3**  
NuMI Rock Cores -Run 2

						$^{7}\text{Be}$	1536	$\pm$	213
						$^{59}\text{Fe}$	5.13	$\pm$	0.95
						$^{48}\text{V}$	28.7	$\pm$	4
						$^{47}\text{Sc}$	246	$\pm$	34
						$^{46}\text{Sc}$	14.4	$\pm$	2.1
						$^{51}\text{Cr}$	79.2	$\pm$	11.6
						$^{44\text{M}}\text{Sc}$	15	$\pm$	3.8
						$^{44}\text{Sc}$	2.38	$\pm$	0.46
						$^{28}\text{Mg}$			
						$^{47}\text{Ca}$	62.6	$\pm$	9.5
						$^{153}\text{Sm}$			
						$^{140}\text{La}$			
						$^{60}\text{Co}$	2.96	$\pm$	0.53
						$^{233}\text{Pa}$	5.32	$\pm$	1.23
						$^{141}\text{Ce}$			
						$^{43}\text{K}$			
970430GL05	Tag #5899	97-090-T9	4.42	$\pm$	0.59	$^{22}\text{Na}$	210	$\pm$	25

970430GL02	Core #S1215- 146'	97-090-A (10)				$^{22}\text{Na}$	106	$\pm$	15
						$^{24}\text{Na}$			
						$^{52}\text{Mn}$	39.3	$\pm$	5.5
						$^{54}\text{Mn}$	16.8	$\pm$	2.4
						$^{7}\text{Be}$	1746	$\pm$	243
						$^{59}\text{Fe}$	3.1	$\pm$	0.69
						$^{48}\text{V}$	19.5	$\pm$	2.8
						$^{47}\text{Sc}$	303	$\pm$	42
						$^{46}\text{Sc}$	10.9	$\pm$	1.5
						$^{51}\text{Cr}$	67	$\pm$	10.1
						$^{44\text{M}}\text{Sc}$			
						$^{44}\text{Sc}$			
						$^{28}\text{Mg}$			
						$^{47}\text{Ca}$	90.8	$\pm$	12.9
						$^{153}\text{Sm}$	56.5	$\pm$	16.5
						$^{140}\text{La}$			
						$^{60}\text{Co}$			
						$^{233}\text{Pa}$			
						$^{141}\text{Ce}$			
						$^{43}\text{K}$			

**Table 3**  
NuMI Rock Cores -Run 2

970430GL05	Tag #5893	97-090-TA (10)	5.18	±	0.69	$^{22}\text{Na}$	246	±	29
<hr/>									
970430GL03	Core #S1215- 173'	97-090-B (11)				$^{22}\text{Na}$	90.6	±	12.7
						$^{24}\text{Na}$			
						$^{52}\text{Mn}$	31.2	±	4.4
						$^{54}\text{Mn}$	14.9	±	2.2
						$^7\text{Be}$	1454	±	202
						$^{59}\text{Fe}$	2.34	±	0.6
						$^{48}\text{V}$	16.3	±	2.5
						$^{47}\text{Sc}$	258	±	36
						$^{46}\text{Sc}$	12.3	±	1.8
						$^{51}\text{Cr}$	54.6	±	8.4
						$^{44}\text{Mg}$			
						$^{44}\text{Sc}$			
						$^{28}\text{Mg}$			
						$^{47}\text{Ca}$	73.5	±	10.9
						$^{153}\text{Sm}$	56.7	±	15.3
						$^{140}\text{La}$	18.6	±	6.3
						$^{60}\text{Co}$			
						$^{233}\text{Pa}$			
						$^{141}\text{Ce}$			
						$^{43}\text{K}$			
970430GL06	Tag #5892	97-090-TB (11)	4.33	±	0.58	$^{22}\text{Na}$	206	±	24
<hr/>									
970430GL03	Core #S1215- 186'	97-090-C (12)				$^{22}\text{Na}$	79.6	±	11.2
						$^{24}\text{Na}$			
						$^{52}\text{Mn}$	18.5	±	2.9
						$^{54}\text{Mn}$	11.5	±	1.7
						$^7\text{Be}$	1333	±	186
						$^{59}\text{Fe}$			
						$^{48}\text{V}$	10.8	±	1.8
						$^{47}\text{Sc}$	262	±	37
						$^{46}\text{Sc}$	4.93	±	1.11
						$^{51}\text{Cr}$	49.2	±	7.8
						$^{44}\text{Mg}$			
						$^{44}\text{Sc}$			

**Table 3**  
NuMI Rock Cores -Run 2

**Table 3**  
NuMI Rock Cores -Run 2

						<sup>54</sup> Mn	62.4	±	8.8
						<sup>7</sup> Be	744	±	104
						<sup>59</sup> Fe	15.3	±	2.7
						<sup>48</sup> V	68.6	±	9.6
						<sup>47</sup> Sc	194	±	27
						<sup>46</sup> Sc	52.2	±	7.3
						<sup>51</sup> Cr	219	±	31
						<sup>44M</sup> Sc	20	±	5.8
						<sup>44</sup> Sc			
						<sup>28</sup> Mg			
						<sup>47</sup> Ca	23.8	±	4.4
						<sup>153</sup> Sm	327	±	55
						<sup>140</sup> La	64.6	±	16.6
						<sup>60</sup> Co	3.28	±	0.81
						<sup>233</sup> Pa	9.2	±	1.8
						<sup>141</sup> Ce	2.34	±	0.65
						<sup>43</sup> K			
970430GL06	Tag #5894	97-090-TE (14)	2.68	±	0.37	<sup>22</sup> Na	127	±	15



**Table 4**  
NuMI Rock Cores - Run 3

Fermilab Sample ID	Core ID	AAL Work Request #	Estimated Beam Flux (equivalent Baryons) (X1013)	Error on Estimated Beam Flux (eq. Baryons) (X1013)	Isotope	Average Specific Activitiy (pCi/gr) (X102)	Specific Activity Error (pCi/gr)
970930GL01	S1214-R6 124.5'	97-269			<sup>22</sup> Na	210	± 29
					<sup>24</sup> Na		
					<sup>54</sup> Mn	28.7	± 4.1
					<sup>7</sup> Be	1772	± 246
					<sup>48</sup> V	5.54	± 1.07
					<sup>47</sup> Sc	15.3	± 3.1
					<sup>46</sup> Sc	16	± 2.4
					<sup>51</sup> Cr	34.2	± 8.9
					<sup>47</sup> Ca	3.71	± 1.24
970930GL01	Tag #5451	97-269-T1	10.8	± 1.4	<sup>22</sup> Na	498	± 58
<hr/>							
970930GL02	S1214-R13 200'	97-269			<sup>22</sup> Na	158	± 22
					<sup>24</sup> Na		
					<sup>52</sup> Mn	2.69	1.23
					<sup>54</sup> Mn	47.3	± 6.7
					<sup>7</sup> Be	1343	± 187
					<sup>48</sup> V	8.51	± 1.42
					<sup>47</sup> Sc	10.8	± 2.6
					<sup>46</sup> Sc	30.6	± 4.3
					<sup>51</sup> Cr	61.4	± 11.2
					<sup>47</sup> Ca		
970930GL02	Tag #5453	97-269-T2	8.04	± 1.06	<sup>22</sup> Na	371	± 43
<hr/>							
970930GL03	S1217-R9 157.5'	97-269			<sup>22</sup> Na	225	± 31
					<sup>24</sup> Na		
					<sup>52</sup> Mn		
					<sup>54</sup> Mn	22.4	± 3.3
					<sup>7</sup> Be	2045	± 284
					<sup>48</sup> V	4.58	± 0.89
					<sup>47</sup> Sc	18.1	± 3.4
					<sup>46</sup> Sc	6.77	± 1.29

**Table 4**

NuMI Rock Cores - Run 3

						$^{51}\text{Cr}$	25.8	$\pm$	8.5
						$^{47}\text{Ca}$	1.8	$\pm$	0.76
970930GL03	Tag #5455	97-269-T3	11	$\pm$	1.4	$^{22}\text{Na}$	508	$\pm$	59
<hr/>									
970930GL04	S1217-R6 125'	97-269				$^{22}\text{Na}$	261	$\pm$	36
						$^{24}\text{Na}$			
						$^{52}\text{Mn}$			
						$^{54}\text{Mn}$	24.5	$\pm$	3.6
						$^7\text{Be}$	2408	$\pm$	334
						$^{48}\text{V}$	5.8	$\pm$	1.21
						$^{47}\text{Sc}$	22.7	$\pm$	4.5
						$^{46}\text{Sc}$	11.2	$\pm$	1.8
						$^{51}\text{Cr}$			
						$^{47}\text{Ca}$			
970930GL04	Tag #5454	97-269-T4	13.2	$\pm$	1.7	$^{22}\text{Na}$	608	$\pm$	70
<hr/>									
970930GL05	S1214-R9 153'	97-269				$^{22}\text{Na}$	179	$\pm$	25
						$^{24}\text{Na}$			
						$^{52}\text{Mn}$	2.4	$\pm$	0.9
						$^{54}\text{Mn}$	24.8	$\pm$	3.6
						$^7\text{Be}$	1573	$\pm$	219
						$^{48}\text{V}$	4.72	$\pm$	0.98
						$^{47}\text{Sc}$	16.9	$\pm$	3.5
						$^{46}\text{Sc}$	11.6	$\pm$	1.8
						$^{51}\text{Cr}$	30.8	$\pm$	7.6
						$^{47}\text{Ca}$	3.19	$\pm$	1.38
970930GL05	Tag #5452	97-269-T5	8.78	$\pm$	1.16	$^{22}\text{Na}$	407	$\pm$	47
<hr/>									
970930GL06	S1217-R14 200'	97-269				$^{22}\text{Na}$	199	$\pm$	27
						$^{24}\text{Na}$			
						$^{52}\text{Mn}$	2.71	$\pm$	1.03
						$^{54}\text{Mn}$	38.6	$\pm$	5.54
						$^7\text{Be}$	1640	$\pm$	228

**Table 4**  
NuMI Rock Cores - Run 3

							$^{48}\text{V}$	7.32	$\pm$	1.39
							$^{47}\text{Sc}$	8.83	$\pm$	3.06
							$^{46}\text{Sc}$	9.54	$\pm$	1.59
							$^{51}\text{Cr}$	48.7	$\pm$	10.9
							$^{47}\text{Ca}$			
970930GL06	Tag #5456	97-269-T6	9.34	$\pm$	1.23		$^{22}\text{Na}$	432	$\pm$	50



Table 5

Depth Profiles for Mean Induced Specific Activity per Equivalent Baryon

Depth below grade (feet)	Sample ID- Work Request #	Estimated Beam Flux (equivalent Baryons) (X10 <sup>-13</sup> )	22Na Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	24Na Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	54Mn Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	52Mn Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	7Be Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	46Sc Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	48V Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	51Cr Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	47Sc Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	47Ca Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	43K Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	59Fe Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	60Co Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	44Sc Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	44MSc Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	153Sm Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	141Ce Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	233Pa Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	140La Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )
71	970430GL01 97-090 -4	4.96	20.6	223.8	2.26	4.64	357	2.7	3.23	7.42	42.7	14.4	14.5				0.32		5.83		3.21
94	970430GL02 97-090 -9	4.42	20		5.09	11.38	348	3.26	6.49	17.92	55.7	14.2				0.54	3.35			1.2	
107	970318GL07 97-057-7	5	21	113.6	3.04	3.7	286	1.56	2.32	8.72	21.2	10.4	10.4						4.5		
121	970430GL02 97-090 -8	3.33	23		2.98	6.79	401	2.84	4.11	9.64	63.1	19.6							16		
124.5	970930GL01 97-269 -1	10.8	19.4		2.66		164	1.48	0.51	3.17	1.4	0.3									
125	970930GL04 97-269 -4	13.2	19.8		1.86		182	0.85	0.44		1.7										
130	970318GL03 97-057-3	6.63	20.1	86.4	5.61	6.91	268	2.67	4.68	18.1	20.2	10.2	7.3			0.26		4.01			
136	970430GL02 97-090 -7	3.1	20.9		3.87	7	355	3.58	4.1	12.58	51.3	16.6								1.17	
138	970318GL05 97-057-5	5.47	22.9	91	3.33	4.13	318	1.86	3.07	7.22	20.8	11.5	7.6						3.36		
142	970430GL02 97-090 -6	2.66	21.5	17	2.46	3.87	367	1.61	2.53	5.6	51.1										
146	970430GL02 97-090-A (10)	5.18	20.5		3.24	7.59	337	2.1	3.76	12.93	58.5	17.5	0.6						10.8		
153	970930GL05 97-269-5	8.78	20.4		2.82	0.27	179	1.32	0.54	3.51	1.9	0.4									
157.5	970930GL03 97-269-3	11	20.5		2.04		186	0.62	0.42	2.35	1.6	0.2									
173	970430GL03 97-090-B (11)	4.33	20.9		3.44	7.21	336	2.84	3.76	12.61	59.6	17		0.54				12.9		4.23	
185	970318GL01 97-057-1	4.96	22.4	92.3	3.79	5.22	275	1.93	3.79	13.71	12.3	6.3	5.8			0.7		4.54			
186	970430GL03 97-090-C (12)	3.87	20.6		2.97	4.78	344	1.27	2.79	12.71	67.7	20.8									

**Table 5**  
Depth Profiles for Mean Induced Specific Activity per Equivalent Baryon

Depth below grade (feet)	Sample ID-Work Request #	Estimated Beam Flux (equivalent Baryons) (X10 <sup>-13</sup> )	22Na Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	24Na Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	54Mn Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	52Mn Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	7Be Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	46Sc Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	48V Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	51Cr Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	47Sc Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	47Ca Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	43K Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	59Fe Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	60Co Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	44MSc Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	153Sm Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	141Ce Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	233Pa Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )	140La Produced by Irradiation (pCi/gr./eq. baryon) (X10 <sup>-13</sup> )		
196	970430GL03 97-090-D (13)	3.46	19.3		2.46	4.6	325	2.03	2.75	6.13	64.7	18.2										
200	970930GL02 97-269-2	8.04	19.7		3.57	0.33	220	1.99	0.69	4.25	1.9											
200	970930GL06 97-269-6	9.34	21.3		4.13	0.29	176	1.02	0.78	5.21	0.9											
221	970430GL02 97-090-5	4.43	19.6	1235.4	5.78	13.18	309	4.72	6.77	24.38	41.3	10.3		0.74		0.35	3.14	16.6		1.2	3.72	
246	970430GL01 97-090-3	3.89	20.7	790.2	7.4	15.01	298	8.28	7.87	23.39	49.1	11.9		1.73		4.73	36	0.52	1.88	11.2		
271	970430GL01 97-090-2	3.47	20.5	1130.5	10.32	22.54	292	10.78	11.53	36.89	51	10.9		2.13	0.35	1.16	3.66	53.9		1.72	11.1	
297	970430GL01 97-090-1	2.94	19	1039.8	26.6	54.76	293	19.25	27.69	93.54	65.6	10.7		8.1		2.09	11.8	93.9			15.7	
321	970430GL03 97-090-E (14)	2.68	18.3		23.28	46.27	278	19.48	25.6	81.72	72.4	8.9		5.71	1.22		7.39	120	0.87	3.43	23.7	

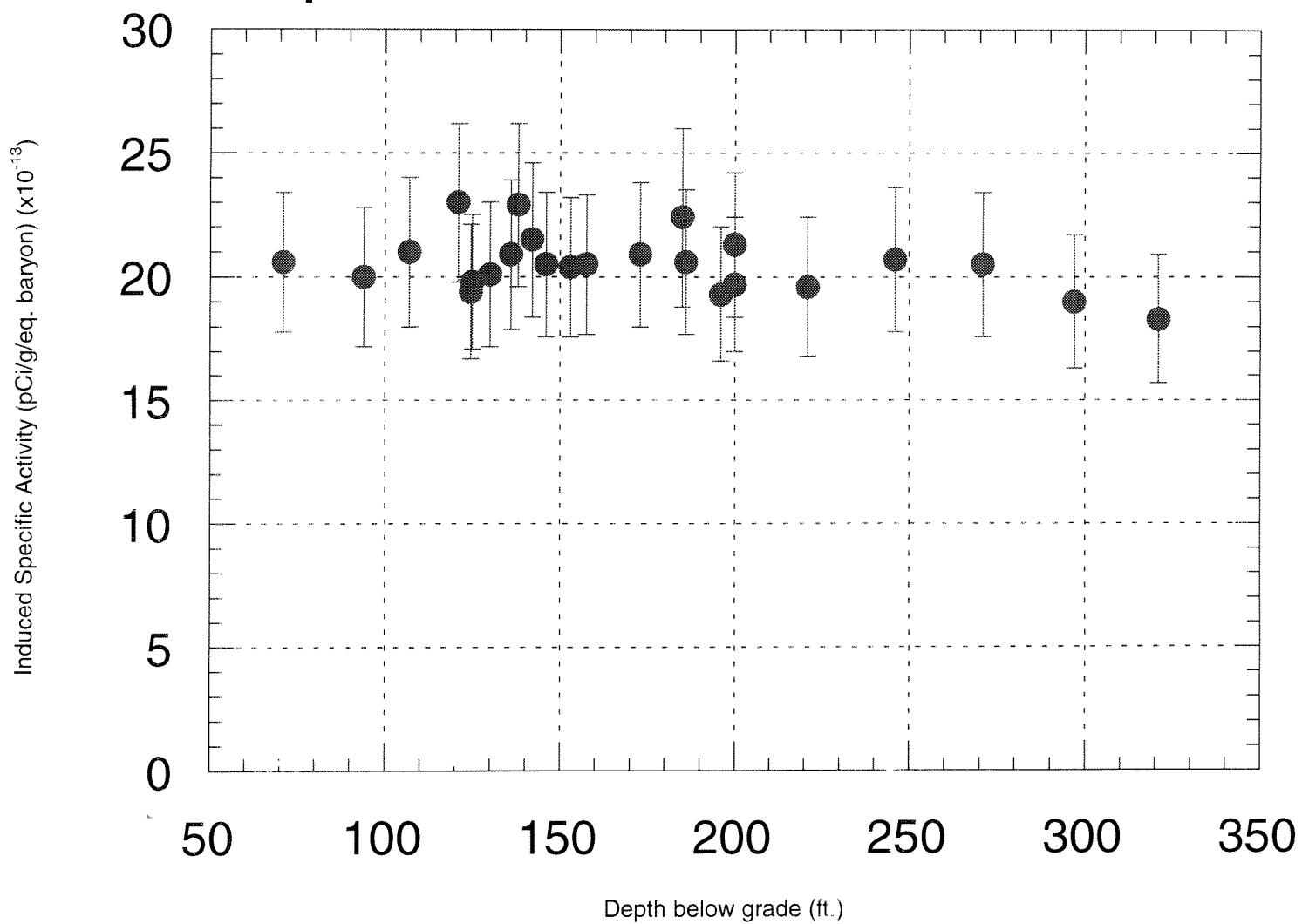
**Table 6**  
Specific Induced Activity for Primary Accelerator Produced Isotopes

Depth below grade (ft.)	Sample ID	<sup>22</sup> Na (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	Error (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	<sup>54</sup> Mn (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	Error (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	<sup>7</sup> Be (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	Error (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	<sup>46</sup> Sc (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	Error (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	<sup>59</sup> Fe (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	Error (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	<sup>60</sup> Co (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	Error (pCi/g/eq. baryon) (x10 <sup>-13</sup> )
71	970430GL01 97-090 -4	20.6	± 2.8	2.26	± 0.34	357	± 49	2.7	± 0.38				
94	970430GL02 97-090 -9	20	± 2.8	5.09	± 0.72	348	± 48	3.26	± 0.48				
107	970318GL07 97-057-7	21	± 3	3.04	± 0.42	286	± 40	1.56	± 0.21				
121	970430GL02 97-090 -8	23	± 3.2	2.98	± 0.45	401	± 56	2.84	± 0.41				
124.5	970930GL01 97-269 -1	19.4	± 2.7	2.66	± 0.38	164	± 23	1.48	± 0.22				
125	970930GL04 97-269 -4	19.8	± 2.7	1.86	± 0.27	182	± 25	0.85	± 0.14				
130	970318GL03 97-057-3	20.1	± 2.9	5.61	± 0.78	268	± 37	2.67	± 0.36				
136	970430GL02 97-090 -7	20.9	± 3	3.87	± 0.58	355	± 49	3.58	± 0.52				
138	970318GL05 97-057-5	22.9	± 3.3	3.33	± 0.46	318	± 44	1.86	± 0.27				
142	970430GL02 97-090 -6	21.5	± 3.1	2.46	± 0.39	367	± 51	1.61	± 0.26				
146	970430GL02 97-090-A (10)	20.5	± 2.9	3.24	± 0.46	337	± 47	2.1	± 0.29	0.6	± 0.13		
153	970930GL05 97-269-5	20.4	± 2.8	2.82	± 0.41	179	± 25	1.32	± 0.21				
157.5	970930GL03 97-269-3	20.5	± 2.8	2.04	± 0.3	186	± 26	0.62	± 0.12				

**Table 6**  
Specific Induced Activity for Primary Accelerator Produced Isotopes

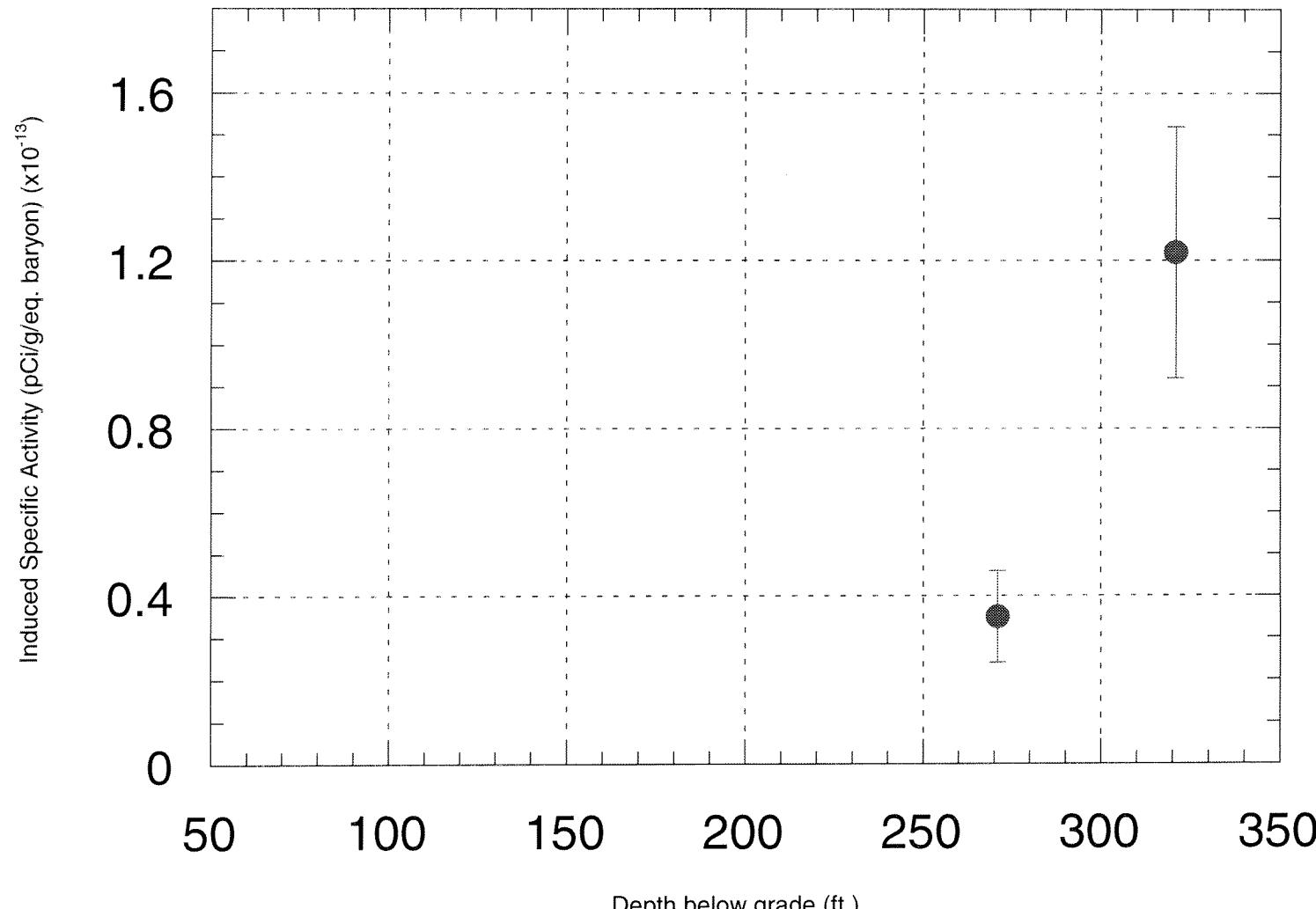
Depth below grade (ft.)	Sample ID	<sup>22</sup> Na (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	Error (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	<sup>54</sup> Mn (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	Error (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	<sup>7</sup> Be (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	Error (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	<sup>46</sup> Sc (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	Error (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	<sup>59</sup> Fe (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	Error (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	<sup>60</sup> Co (pCi/g/eq. baryon) (x10 <sup>-13</sup> )	Error (pCi/g/eq. baryon) (x10 <sup>-13</sup> )
173	970430GL03 97-090-B (11)	20.9 ± 2.9		3.44 ± 0.51		336 ± 47		2.84 ± 0.42		0.54 ± 0.14			
185	970318GL01 97-057-1	22.4 ± 3.6		3.79 ± 0.62		275 ± 45		1.93 ± 0.32					
186	970430GL03 97-090-C (12)	20.6 ± 2.9		2.97 ± 0.44		344 ± 48		1.27 ± 0.29					
196	970430GL03 97-090-D (13)	19.3 ± 2.7		2.46 ± 0.37		325 ± 45		2.03 ± 0.31					
200	970930GL02 97-269-2	19.7 ± 2.7		5.88 ± 0.83		167 ± 23		3.81 ± 0.53					
200	970930GL06 97-269-6	21.3 ± 2.9		4.13 ± 0.59		176 ± 24		1.02 ± 0.17					
221	970430GL02 97-090-5	19.6 ± 2.8		5.78 ± 0.81		309 ± 43		4.72 ± 0.7		0.74 ± 0.21			
246	970430GL01 97-090-3	20.7 ± 2.9		7.4 ± 1.05		298 ± 41		8.28 ± 1.16		1.73 ± 0.35			
271	970430GL01 97-090-2	20.5 ± 2.9		10.3 ± 1.4		292 ± 41		10.8 ± 1.5		2.13 ± 0.35		0.35 ± 0.11	
297	970430GL01 97-090-1	19 ± 2.7		26.6 ± 3.7		293 ± 40		19.3 ± 2.6		8.1 ± 1.22			
321	970430GL03 97-090-E (14)	18.3 ± 2.6		23.3 ± 3.3		278 ± 39		19.5 ± 2.7		5.71 ± 1.01		1.22 ± 0.3	

## Depth Profile for $^{22}\text{Na}$ Production in Dolemite



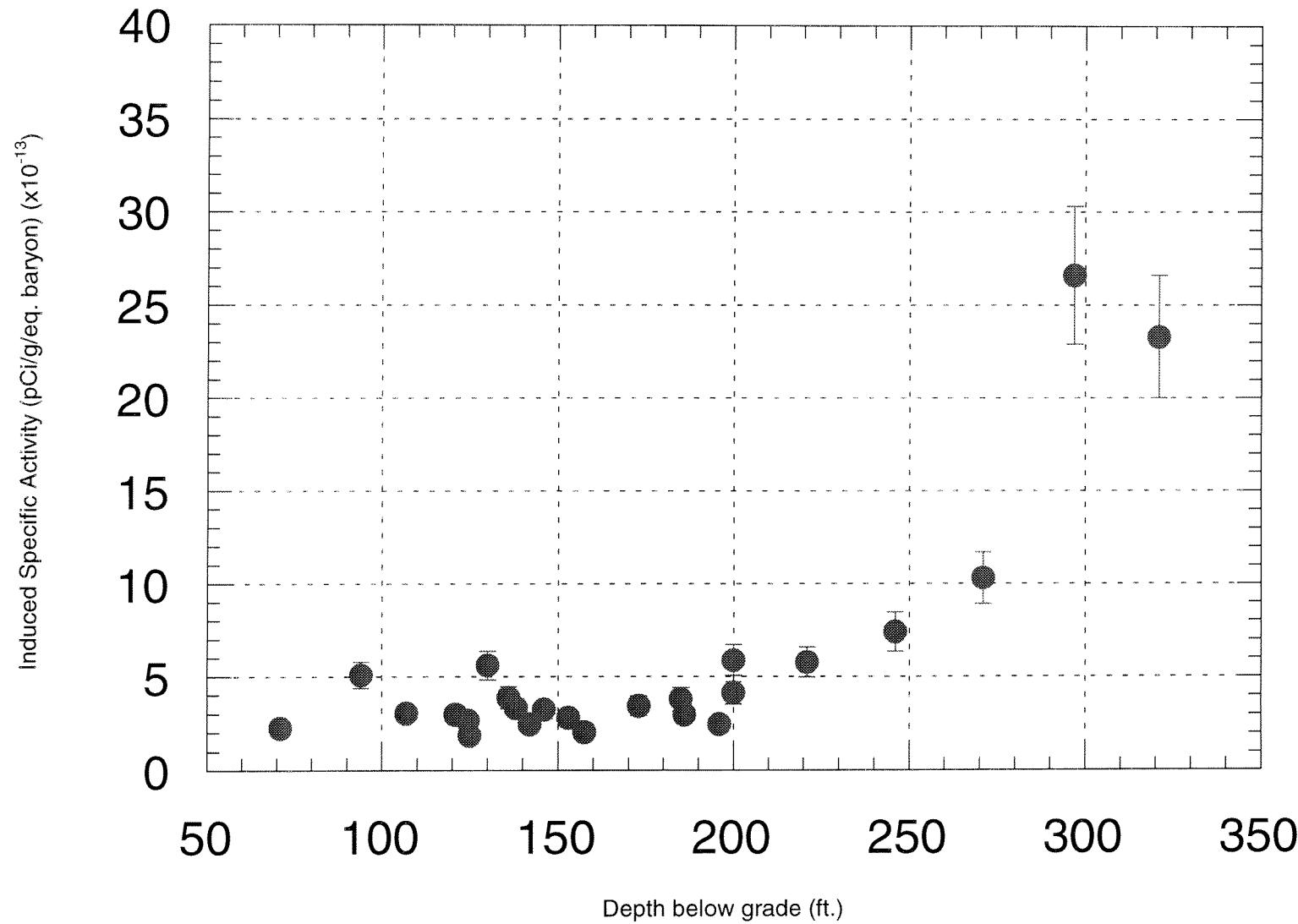
**Graph 1**

## Depth Profile for $^{60}\text{Co}$ Production in Dolemite



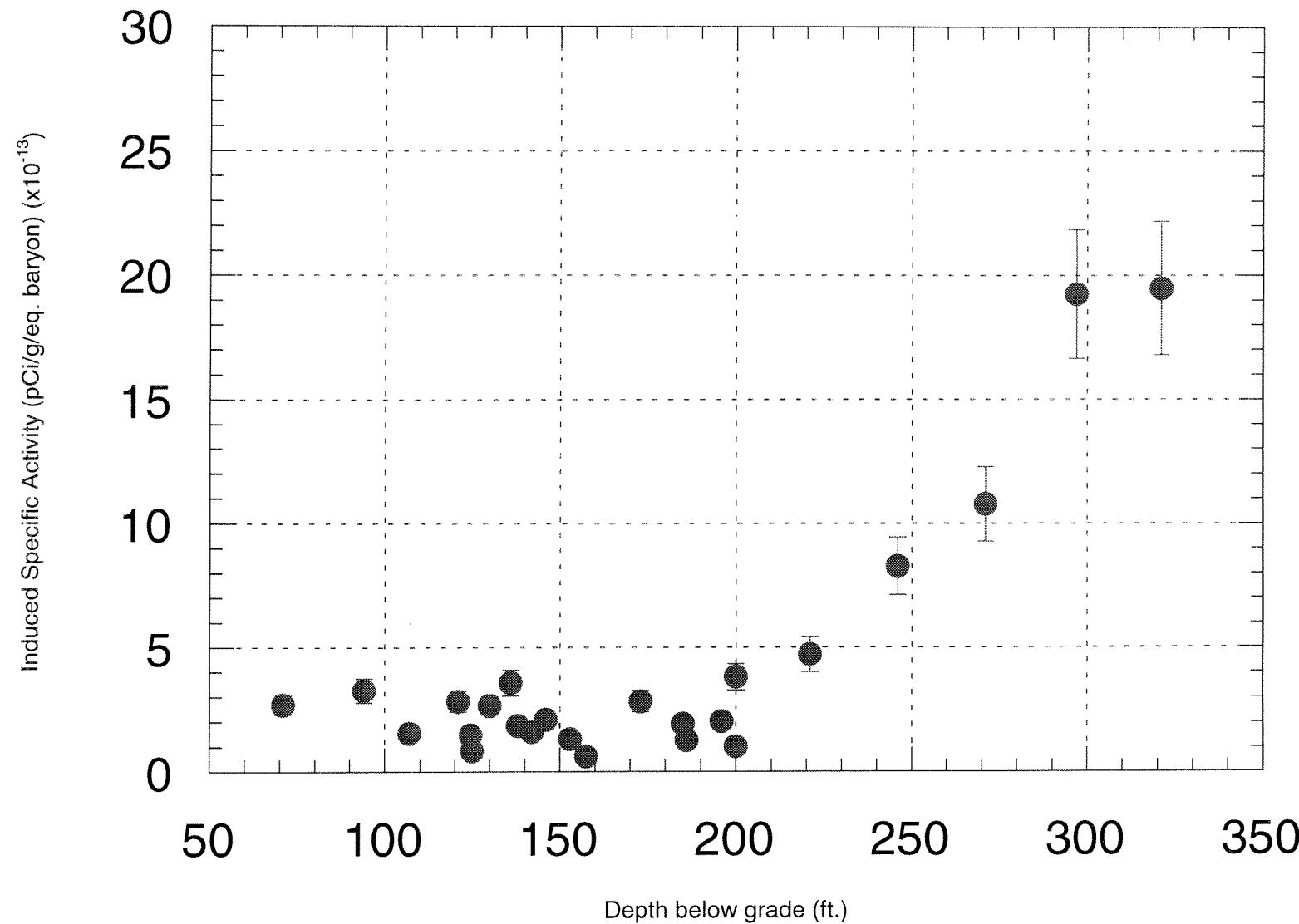
**Graph 2**

## Depth Profile for $^{54}\text{Mn}$ Production in Dolemite



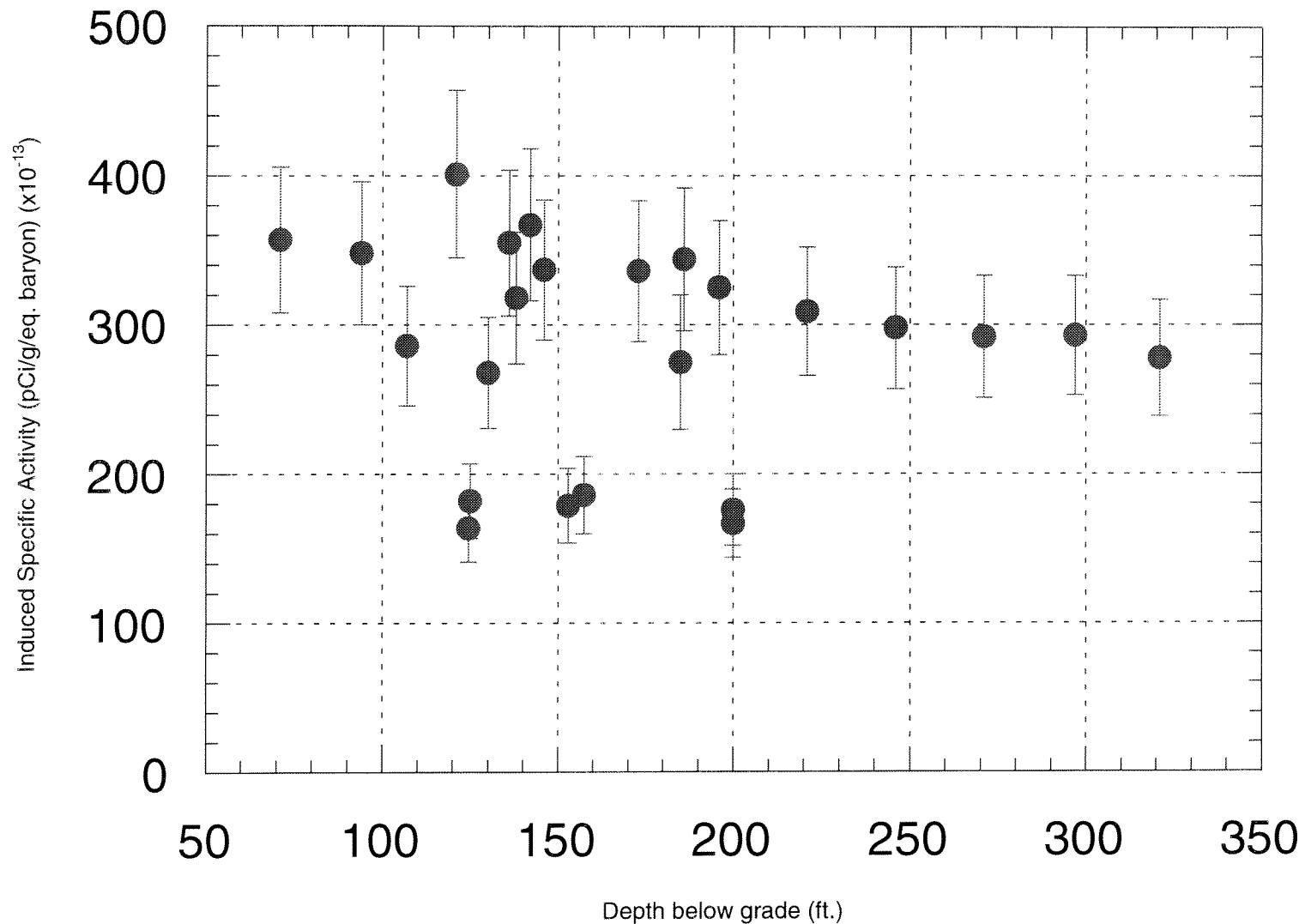
**Graph 3**

## Depth Profile for $^{46}\text{Sc}$ Production in Dolemite



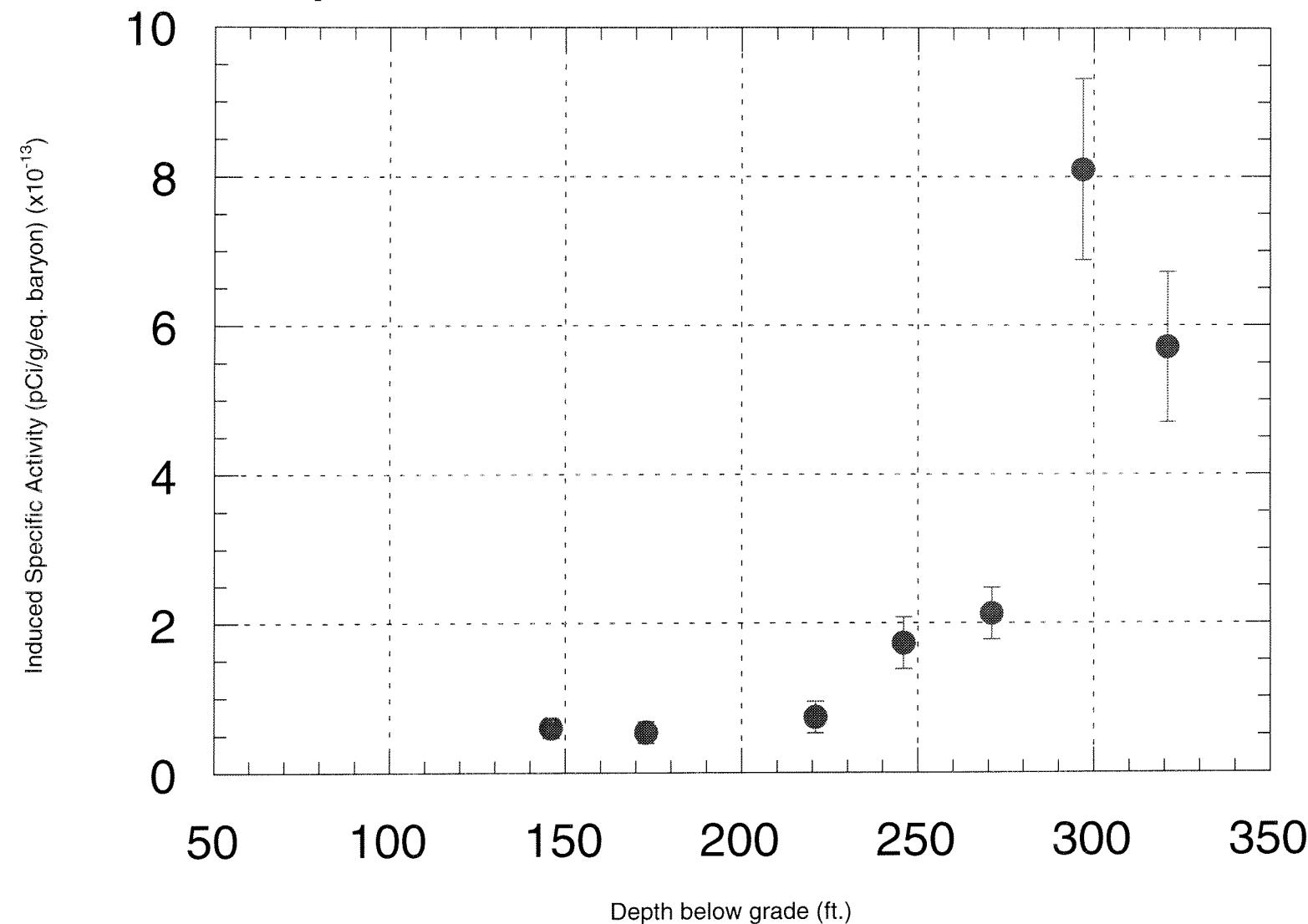
**Graph 4**

## Depth Profile for ${}^7\text{Be}$ Production in Dolemite



**Graph 5**

## Depth Profile for $^{59}\text{Fe}$ Production in Dolemite



## Graph 6